# VERMICULITE

BY O. S. NORTH AND H. P. CHANDLER

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# INTRODUCTION

As recently as the late 1920's there were few indications that a 15-million-dollar-a-year industry would ever grow out of the mineralogic curiosity vermiculite. Today, it is an important industrial commodity, used primarily as an insulating material and lightweight aggregate, but with a wide range of other applications. The quantity of crude vermiculite produced and used in the United States increased 14-fold in the 17 years between 1935 and 1951.

The vermiculite minerals are of secondary origin, formed by hydrothermal alteration of an ultrabasic igneous rock, generally pyroxenite, or by alteration of phlogopite or biotite mica or possibly other similar minerals. According to different authorities, vermiculite may originate either by direct hydrothermal means, by the weathering of biotite or phlogopite, or by a combination of these two agencies. Vermiculites frequently occur at or near the contacts of an acid intrusive rock, especially a pegmatite dike, with a basic or ultrabasic country rock.

Vermiculite was first described by T. H. Webb in 1824, but it was not until 1913, when the first large deposit was discovered in the Turret mining district of Colorado, that efforts were made to develop the material commercially. Exfoliated vermiculite was first marketed in 1915 from a deposit 5 miles southeast of Hecla, Colo., in the Turret district. That activity was brief, but successful and continuous commercial development began in 1921 in Montana. Deposits have been developed in other States from time to time; but they have proved only moderately successful, and at present the bulk of the production in the United States comes from Montana. The only other State producing appreciable quantities of crude vermiculite is South Carolina. Output in North Carolina has declined to only a few hundred tons annually.

Vermiculite has been found in the Union of South Africa, Tanganyika, Kenya, Uganda, Rhodesia, Canada, India, Australia, Mexico, Chile, Brazil, Japan, and other countries.

Many varieties of vermiculite, perhaps more properly termed the "vermiculite minerals," have been identified. Various names have been assigned to them, but many of the names merely connote the locality in which the variety was first found or the name of the finder. The term "vermiculite,' as used in this report, includes not only the true vermiculite but any other material of essentially similar characteristics, particularly any that may now be, or was in the past, commercially processed and sold.

## ACKNOWLEDGMENTS

Parts of this information circular have been adapted with only minor changes from another Bureau of Mines information circular.2/ The authors are also indebted to J. A. Kelley, of the Zonolite Co., and C. A. Pratt, of Western Mineral Products Co., who contributed valuable information and helpful suggestions.

## MINERALOGY AND PROPERTIES

The vermiculite minerals are hydrated magnesium-aluminum silicates. They show the characteristic micaceous structure of basal cleavage and occur as soft, pliable, inelastic laminae. Vermiculite crystallizes in the monoclinic system, and the crystal faces are often marked with triangular lines at 60° and 120°. Its hardness ranges from 1.5 to 3.0, and the specific gravity of crude material, as mined, is about 2.5. Vermiculite in the crude state ranges in color from dark yellowish-brown to light brownish-yellow to green or bronze. When heated in an open tube, its color changes to golden brown, whereas heating in a closed tube or other reducing atmosphere produces a silvery hue. The fusion point is approximately 2,462° F.

The question of whether vermiculites are distinct minerals has puzzled mineralogists for many years, and their claim to be ranked as separate minerals has been doubted, but X-ray studies by Gruner3/ and by Hendricks and Jefferson4/ indicate that they constitute a specific type with a definite structure differing from that of mica or chlorite. From the tabulation of a number of analyses, Gruner has stated that their average composition can be represented by the formula $22MgO.5Al_2O_3.Fe_2O_3.22SiO_2.40H_2O$, whereas J. B. Myers, Zonolite Co., gives the structural formula as $(OH)_2(Mg,Fe)_3(Si,Al,Fe)_4O_{10}.4H_2O$.5/ The indefinite and variable chemical composition of vermiculite is indicated by the following ranges in the percentages present of each of the major components: Silica, 31-41; alumina, 10-17; iron oxides, 5-22; magnesium oxide, 11-31; and total water content (free water and water of crystallization), 4-21.6/ Nineteen varieties of vermiculite have been identified and listed, as follows: Buldymite, culsageeite, dudleyite, eastonite, hallite, jefferisite, kerrite, lennilite, lucasite, maconite, painterite, pelhamite, philadelphite, protovermiculite, pyrosclerite, roseite, vaalite, vermiculite, and willcoxite. Of the 19 varieties, commercially valuable deposits of only vermiculite and jefferisite have been found; most of the crude mineral now being used is hydrobiotite, a metacryst (a pseudophenocryst of a secondary mineral) of true vermiculite and biotite.

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2/ Gwinn, G. R., Marketing Vermiculite: Bureau of Mines Inf. Circ. 7270, 1944, 15 pp.

3/ Gruner, J. W., The Structure of Vermiculites and Their Collapse by Dehydration: Am. Mineral., vol. 19, No. 12, 1934, pp. 557-575.

4/ Hendricks, S. B., and Jefferson, M. E., Crystal Structure of Vermiculites and Mixed Vermiculite Chlorites: Am. Mineral., pt. 1, vol. 23, No. 12, 1938, pp. 851-862.

5/ Myers, J. B., Chapter on Vermiculite in Industrial Minerals and Rocks: Am. Inst. Min. and Met. Eng., New York, 1949, p. 1102.

6/ Varley, E. R., Vermiculite: Colonial Geol. Survey (London), Min. Resources Div., 1952, pp. 4-5.

Vermiculite expands when heated, giving off considerable water. This expansion or exfoliation is believed to be a mechanical separation of the layers when the contained water is converted into steam. Warping of the unit layers also may contribute to the expansion. The increased volume due to exfoliation ranges from 6 to 20 times that of the unexpanded material, the increase in bulk volume of commercial material usually being 8 to 12 times, although individual flakes may show greater increase in size. The expansion is axial, normal to the basal cleavage, and the change in the other two dimensions is negligible. The color changes to a silvery or golden hue, according to the chemical nature of the ore, the degree of heating, and the conditions of exposure to air.

Chemical composition alone is of little value in determining commercial quality of a vermiculite. A technical trial of possible material provides the only satisfactory test.

## GEOLOGIC OCCURRENCE AND ORIGIN

Vermiculite commonly is associated with intrusions of ultrabasic igneous rocks, such as dunites, serpentines, peridotites, and pyroxenites. It may occur as a zone or envelope of alteration products surrounding the basic intrusion or as irregular veins within the intrusive body. Quartz, feldspar, corundum, apatite (particularly fluorapatite), biotite, chlorite, asbestos, and talc are typical associated minerals.

In a few known occurrences vermiculite is not associated with a basic rock, but the quantity of the material is not large, and its exfoliation properties are inferior or almost wholly absent.

The vermiculite and associated micas, which are classed as hydrobiotites, from the Libby deposit in Montana are believed to have been formed by hydrothermal alteration of an ultrabasic igneous rock, in this instance pyroxenite. Formerly they were thought to be alteration products of biotite and phlogopite mica, but a detailed study of the deposit showed that the vermiculite was derived from the pyroxenite and that the associated biotite was formed at about the same time. Whether the alteration produced vermiculite or biotite and the proportions and segregations of each were determined largely by the chemical composition of the hydrothermal solution. The South African golden-yellow vermiculite is regarded as an altered phlogopite. Vermiculites in North Carolina are reported to have been formed by hydration and alteration of chlorite.

It is likely that vermiculite minerals have been formed by a number of different geological processes. However, in all cases vermiculites are secondary minerals resulting from hydrothermal alteration and weathering. The compositions of the rocks or primary minerals from which a vermiculite is derived, the chemical nature of the altering solution, and the degree of alteration account for the variation in chemical composition and physical properties of the many varieties.

## HISTORY

Vermiculite was first described by Thomas H. Webb in 1824. He found the mineral in a talc deposit near Worcester, Mass., and described it as follows:

> The mass has a brownish cast and is composed of two parts. The one is compact, of a dirty white and yellowish color, constituting the base; the other is in thin plates of a yellowish and blackish cast and resembles mica very much in appearance. When pulverized it seems to consist of a yellowish powder interspersed with small shining laminae. If subjected to the flame of a blowpipe or that of a common lamp it expands and shoots out into a veriety of fanciful forms - resembling most generally small worms having the vermicular motion exact. The vermiform remnants are composed of small irregular scales, loosely adhering to each other, having a silvery white appearance and metallic luster. If this proves to be a new variety, would it not be better to give it a distinctive appellation, to select one that will indicate the peculiar property it possesses than to make use of an arbitrary name? I term it vermiculite (worm breeder) from vermicular, to breed or produce worms.

Jefferisite was first found in 1851 by W. W. Jefferis in a serpentine quarry near West Chester, Pa., in a vein about 2 feet wide composed of platy, bronze-yellow material. A sample was sent to Prof. G. J. Brush, of Yale College, for analysis and identification. Professor Brush tentatively identified it as a biaxial chlorite member of the hydrous magnesium silicates and thought that it was vermiculite because of its exfoliating properties. In 1861 Professor Brush decided that, on the basis of optical properties, it was not vermiculite but a new mineral, since vermiculite at that time was thought to be a uniaxial mineral (although it is now known to be biaxial with a very small axial angle). Brush proposed the name jefferisite and described its properties as follows: A bronze-yellow material optically biaxial, with a small axial angle; resembles phlogopite; exfoliates before a spirit lamp and resembles vermiculite; occurs in six-sided prisms with a micalike structure and basal cleavage; has a specific gravity of 2.30 and a hardness of 1.5.

Culsageeite was found in North Carolina in 1873 by C. W. Jenks, manager of the American Corundum Co. mine near the Culsagee River in Macon County. The mineral was described and named by Dr. F. A. Genth. Culsageeite, ripidolite, and chlorite are associated as gangue minerals in the corundum deposits of North Carolina and Georgia and have been used as guide minerals in prospecting for corundum.

Nickeliferous vermiculite has been found in several dunite deposits in North Carolina. The largest showing (and it is not of commercial importance) is at Webster, Jackson County,7/ where nickel-bearing vermiculite occurs in narrow veins in the fractured dunite. It displays a transition of colors from bright green in the nickel veins and the residual red soil of completely weathered dunite to dark green near the contact with fresh dunite to dark bronze in fresh dunite.

Buldymite occurs in corundum-plagioclase veins of the Buldym district, U.S.S.R.; lennilite is found near Lenni, Pa.; kerrite veins are located near Franklin, N. C.; philadelphite has been identified near Philadelphia, Pa.; vaalite occurs at Du Poits Pan, South Africa; and protovermiculite has been found at Magnet Cove, Ark.

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7/ Ross, C. S., and Shannon, E. V., Nickeliferous Vermiculite and Serpentine: Am. Mineral., vol. 11, No. 4, 1926, pp. 90-93.

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## DOMESTIC DEPOSITS

Vermiculite has been reported in 12 States in the United States, and commercial production is known to have come from 7. The deposits vary considerably in composition, and variations occur also within a single deposit.

### Colorado

Vermiculite in commercial quantities was first discovered in 1913 in Colorado. The deposits are in the Rocky Mountains in Chaffee, Custer, Fremont, and Gunnison Counties. The first find, which was of the jefferisite variety occurring as a vein 20 inches wide, was made by W. B. Thomas in the Turret mining district in Chaffee County, 14 miles north of Salida. Because of high operating costs, only a small tonnage was produced. Vermiculite was first marketed in 1915 by the Denver Mining & Manufacturing Co. from a deposit discovered in 1913 in the same mining district, 5 miles southeast of Hecla. The material was marketed under the trade name tung ash and was classified at the time as a hydrated biotite mica.

A large deposit of high-grade vermiculite was discovered in Fremont County in 1934. The material was first sent to Omaha, Nebr., for processing, but a local expansion plant was later constructed. A deposit of jefferisite 7 miles east of Westcliffe, Custer County, was developed in the 1920's. Neither of those deposits is now in commercial operation.

Other deposits have been located in the Iola district of Gunnison County, near Feldspar, Canon City, and Beulah, and in a number of other localities. Production in Colorado has been intermittent, although reserves have been estimated at 440,000 tons.

### Montana

Continuous production on a commercial scale began in 1921 from deposits in the Rainy Creek district in Lincoln County, Mont., about 7 miles northeast of Libby. These deposits were discovered by E. N. Alley in 1916 while prospecting for vanadium minerals. Alley and a group of associates formed the Zonolite Co. A second firm, the Vermiculite & Asbestos Co. later known as the Universal Insulation Co., operated on the same deposits. Eventually the firms merged, and the name Zonolite Co. was adopted a few years after the merger.

The main deposit is a large, rounded hill, almost all of which contains vermiculite. It is associated with small porphyry dikes and a single large stock of pyroxenite and syenite, which intrudes argillites and quartzites. The largest concentration of the mineral is at the eastern end of the deposit, where bodies containing as much as 95 percent vermiculite are encountered. Other sections of the deposit are lower grade, ranging from 30 to 60 percent vermiculite. About 2 tons of material is mined for each ton of finished concentrates shipped. The entire top of the hill is being removed by bench mining. Complications are the presence of syenite dikes and zones of pyroxenite altered to biotite instead of to vermiculite. This is the largest known deposit of vermiculite in the United States. Reserves have been estimated at

25 to 100 million tons. The Zonolite Co. is by far the major producer of crude and exfoliated vermiculite in the United States.

In Montana vermiculite also occurs in the southern extension of the Madison and Gallatin Ranges north of Yellowstone National Park, on the Rocky Boy Indian Reservation in Hill County, and in a locality about 12 miles east of Hamilton, Ravalli County.

### Wyoming

Vermiculite is associated with igneous and metamorphic rocks in several localities in Wyoming, but those of commercial interest have been found chiefly in four districts - Encampment, Wheatland, Glenrock, and the Sweetwater Uplift. The vermiculite occurs in streaks, patches, and layers of varying thickness and in bodies that are irregular and tend to pinch and swell or end abruptly in depth.

### South Carolina

In the vicinity of Greenville, S. C., bodies of vermiculite are found near the surface at a number of locations in Greenville, Spartanburg, and Laurens Counties. Material from these localities enjoys freight-rate advantages in the Eastern States. The crude material is mined by open-pit methods and hauled to the mill at Travelers Rest for concentration. South Carolina crude vermiculite does not produce particles of the large size preferred for fill insulation, but it is reported to equal in quality the Montana vermiculite when used as a plaster or concrete aggregate. A quantity of crude from these deposits is also processed into fertilizer and soil additives. Estimates of reserves in this area are not available.

### Other Eastern States

In 1873 the maconite variety of the mineral was identified in the Corundum Hill district of North Carolina. Production from eastern deposits was first reported in 1929 from the Brinton Quarry at West Chester, Pa., the locality in which jefferisite was first found. Continuous production in the East began in 1933 from deposits at Ellijay, Macon County, and Swannanoa, Buncombe County, N. C. Numerous occurrences also have been found in Avery, Clay, and Jackson Counties, N. C., and in Towns and Rabun Counties, Ga. Some of these vermiculites are appreciably nickeliferous, having been produced by the base exchange of nickel (set free by the weathering of dunite) for magnesium.

Production in Wyoming, California, Nevada, Colorado, North Carolina, Texas, and Georgia has been small and intermittent, as it also was in South Carolina until very recently, when the Zonolite Co. increased its output from deposits near Travelers Rest, Enoree, and Tigerville.

## FOREIGN DEPOSITS

A mineral that exfoliates when thrown into the fire was mentioned by Pumpelly in his report of a reconnaissance survey for the Japanese Government in 1865. The material was found in a body of serpentine in the mountains of the Kadzua Peninsula south of Yedo.[8] Tsunashiro Wadi, in 1904, described a vermiculite found at Hajikano in the Province of Kai, Japan, known locally as "Hiru-ishi," or leech stone.[9] Vermiculite has also been found in the Ural Mountians in the U.S.S.R., in the Union of South Africa and Tanganyika, and at Bulong and Kalgoorlie in the southeastern part of Western Australia.

Only the Russian and South African deposits are known to have been worked to any extent on a commercial scale. Some years ago the Australian deposits were said to have been under development for use in the local market, but no further pertinent information has been forthcoming. One report states that 95 tons of vermiculite was produced from a deposit at Bulong during 1939 and 1940, but the material appears to have been of doubtful quality. Samples from several other deposits in Western Australia have been tested.

In the Ural Mountains of Soviet Russia vermiculite is associated with dunite and pyroxenite intrusions, which are widely known as sources of platinum. Very little is known concerning the size and number of the vermiculite deposits, but the product is marketed as loose fill and refractory bricks. Small tonnages of low-grade Russian vermiculite have been received in the United States.

Vermiculite is apparently widespread in the colonial territories of the United Kingdom in Africa. These occurrences are described at considerable length by Varley,[10] who also describes the deposits in Cape Province, Natal, and the Transvaal, all in the Union of South Africa. Vermiculite was first reported in the Union from the corundum fields of northern and eastern Transvaal, where it occurs as a thin casing around the corundum reefs. Large deposits were later found in the pyroxenite and serpentine rocks of the Palabora region in northeastern Transvaal. In this area it seems to have been formed by the hydration of biotite or phlogopite, but the origin and relationships of the minerals and rocks remains a highly controversial subject. Production of vermiculite in the Palabora region began about 1938, and rather large quantities were mined in the years following World War II for export to Great Britain, the United States, Canada, and a number of other countries. Over 18,000 short tons were exported to the United States from this source in 1950.

Late in 1950 a deposit of vermiculite of commercial interest was located near Stanleyville, a few miles from Perth, Lanark County, Ontario, Canada. The property was acquired by a Canadian company that formerly processed South African vermiculite. Reserves were estimated at 300,000 tons.

## MINING AND MILLING

Although underground mining of vermiculite was practiced at some mines in the past, virtually the entire quantity now being produced is from opencut

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[8] Pumpelly, R., Across America and Asia: Leypoldt & Holt, New York, 1870, 454 pp.

[9] Wadi, T., Minerals of Japan: Tokyo, 1904, p. 116.

[10] Varley, E. R., work cited in footnote 5, pp. 28-35.

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operations. The procedure described below is followed in mining and milling the vermiculite at the Libby, Mont., deposit.[11]

Very little stripping of overburden is necessary, and the vermiculite, which is soft and spongy, is dug and loaded into motor trucks by power shovels working on 18-foot benches. Only the waste material, a rock that is mostly irregularly occurring syenite intrusions, must be drilled and blasted. Overburden and waste are disposed of in a nearby canyon. As the quality of the ore varies from place to place, it is mined selectively as high grade, medium, or low grade.

Preliminary screening is done near the mine. The vermiculite, which is effectively disintegrated during digging and loading, passes through the 12-inch grizzly at the primary plant. A double-deck, vibrating grizzly with 4- and 2-inch openings effects the primary separation, oversize from the top screen usually being rock waste. The 2-inch oversize, depending on the quality of the ore, may be either wasted or ground in a hammer mill and rescreened. All of the material passing the 2-inch screen is fed via a vertical chute into the mountain to a 24-inch wide, 1,300-foot long, belt conveyor, which delivers it to the mill. A section of the conveyor is below ground, and the remainder is enclosed, permitting continuous operation during rigorous winters.

The percentage of free moisture in crude vermiculite is variable, depending largely on weather conditions. Most of the free water is removed to facilitate grinding, screening, and sizing and to eliminate the greater part of the useless moisture load, which would otherwise be carried through later beneficiation steps and eventually sent to the exfoliator.

At the mill the material first is dried in rotary, oil-fired, parallel-flow kilns. The charge is subjected to a heat of 400° to 600° F. for a short time. Care is exercised to avoid temperatures high enough to disturb the combined moisture content and thereby retard full expansion. Less than 10 percent of the original quantity of free moisture is still present at the point of discharge from the drier. The dried material is screened to size in a battery of vibrating screens before concentration.

These double-deck screens, plus some air-separation units, separate the ore into the sizes most in demand. A cyclone dust-collecting system connects the various mill components. After sizing, the vermiculite is concentrated in a multiple installation of selective crushers. The soft, flaky vermiculite passes the crushers without structural damage or alteration of size or shape, and any cubical particles of rock are shattered to dust and removed, leaving only concentrates. The finished material is conveyed to truck-loading bins, thence to railhead storage bins, from which it is shipped in box cars or hopper cars to exfoliating plants.

The most successful exfoliation occurs when the material fed to the furnace is dry, uniformly sized, and reasonably free of rock and other unexpendable matter.

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[11] Utley, H. F., From Remote Mountain Mine to World-Wide Market: Pit and Quarry, vol. 44, No. 6, December 1951, pp. 78-82.

## EXFOLIATION

In the crude state vermiculite has few uses, its principal commercial usefulness depending on its ability when heated to exfoliate into a lightweight, bulky material of specific properties and particular applications. Commercial exfoliation of vermiculite is accomplished by passing a graded material through one of the several types of kilns - most of which are covered by patents. Usually the kiln is heated with oil or gas, although electricity or pulverized coal also may be used.

The properties desired in the expanded material are light weight, toughness, and complete expansion. The exfoliating properties of vermiculites vary, not only from deposit to deposit but within a single body; some expand more than others, the temperature at which expansion begins or reaches its maximum varies, and still others decrepitate when expanded. Therefore, considerable fuel or power may be saved if before using material from individual or composite sources the temperature is determined at which the greatest exfoliation occurs while maximum toughness is retained. Thus, materials from various sources may be advantageously blended.

Exfoliation is produced most successfully at temperatures between 1,600° F. and 2,000° F. The charge is subjected to heat for 4 to 8 seconds and then cooled rapidly. This imparts pliability and toughness to the expanded particles, prevents scorching or burning bags, and permits the necessary subsequent manual handling. If the kiln temperature is too high or particles are held too long in the heat zone, they show excessive drying out, probably because the high or sustained heat drives out more of the combined water content than is effective in accomplishing the exfoliation. Such particles have undesired brittleness.

Several types of exfoliators are in use, and although they vary in structural details they are similar in principle. The expander in general use in the United States is a modified vertical shaft furnace heated by oil-fired burners. The charge fed into the top of the furnace is impeded in falling by staggered baffles and upon coming in contact with heat from the burners exfoliates. The exfoliated material cools rapidly in its fall from the heated zone to a bucket elevator below, which carries it to a cyclone airlift. The airlift has three functions: It removes unexpanded rock particles, cools the product, and elevates the material for further processing. The product may be classified according to particle sizes with gyratory sifters or with air classifiers. The entire operation, from crude ore in the storage bin to the bagged product, requires but a few minutes.

A second type of expander now in use in the United States consists of a double-wall cylinder with an air space between the walls. The inner cylinder contains conical baffles that impede the fall of the particles, which are charged in at the top of the furnace. The burners may be fired with gas or oil. The air for the burners is preheated as it passes through the annular space between the walls of the cylinders.

Another apparatus consists of a kiln in which a hot, tangential blast creates a vortex of ascending gases that picks up the mineral and carries it upward through progressively hotter zones and eventually to the highest level of the kiln, after which it is bagged.

Most commercial furnaces have rated capacities of over seventy 4-cu. ft. bags of finished material per hour.

The color of the expanded material ranges from nearly silver to deep bronze or gold, depending partly on conditions during processing and partly on the chemical composition of the crude material. Calcining in an excess of air gives a golden product, owing to oxidation of the iron content, whereas the same material will show a silvery hue when air is excluded. However, varieties poor in iron - such as those from the Transvaal and North Carolina - are said to give a silvery product, regardless of the quantity of air available, whereas varieties rich in iron will nearly always give bronze-colored particles.

Because of its light weight and consequent bulk, it is impractical to ship expanded vermiculite far. Therefore, expanding plants have been established at market centers to process the screened and cleaned material.

## USES

The low bulk density, comparatively high refractoriness, low thermal conductivity, and chemical inertness make vermiculite satisfactory for many types of thermal and acoustic insulation.

### Loose Fill

No official statistics on the use patterns of exfoliated vermiculite are available; but one of the earliest applications, and one still popular, is its use in loose, granular form as a fill material in the voids of concrete blocks, in hollow walls, between joists in unfloored attics, and between suitable boards, sheets, lath, wire netting or expanded metal, for the thermal insulation of roofs, ceilings, and walls of buildings. The size range desired for this purpose is minus-3- plus-14-mesh and the bulk density 5 to 6 lb. per cu. ft. The K-factor varies with bulk density and temperature.

In addition to its uses in insulating dwellings, farm buildings, and commercial and industrial structures, loose vermiculite is used for packing refrigerators, ovens, incubators, fireless cookers, thermal jugs, life preservers, safes and water heaters and in many of those uses competes with cork, mineral wool, balsam wool, diatomite, etc. Exfoliated vermiculite may be used to cover the surface of the electrolyte in galvanizing baths to reduce radiation losses and prevent oxidation while the bath is not in use. Loose vermiculite is suitable for packing rail joints, behind fishplates. It may be used as a carrier for insecticides or other agricultural chemicals.

### Concrete

The use of exfoliated vermiculite, chemically treated with a stabilizing admixture, as an aggregate in lightweight concrete is now one of the major quantity applications of the mineral. Vermiculite concretes include monolithic walls, floors and roofs, and prefabricated units such as panels, planks, beams, wall backup blocks, and floor and roof tiles. The use of such a relatively high-priced aggregate is justified in part by the reduction in weight of walls, floors and ceilings, which makes possible appreciable savings in the weight of steel required and therefore in the overall cost. At the same time, concrete of this type is more fire-resistant and has heat-and-sound-insulating properties superior to those of concrete of standard composition.

Vermiculite concrete weighs 16 to 50 pounds per cubic foot. It has a compressive strength of 50 to 500 pounds per square inch and a thermal conductivity (K-factor) of 0.60 to 1.9 B.t.u. per square foot per inch thickness per hour per degree F., depending mainly on the mix ratio and the weight of the concrete; the lighter the concrete the better (that is, lower) the K-factor.[12] Vermiculite concrete is made like ordinary concrete, with expanded vermiculite of 5- to 20-mesh size used as aggregate in place of sand, gravel, or stone. It is used most commonly as insulating roof fill, soundproofing and insulating floor component, or insulating structural roof deck. Precast vermiculite concrete slabs have been used in erecting prefabricated houses, and structural panels of vermiculite concrete, adequately reinforced, on a thin sheet steel or aluminum backing have been used in constructing walls of multistory buildings. Cants, saddles, and slopes for roof drainage also may be made from this concrete. When poured around steel girders, vermiculite concrete provides fire protection. Slabs and blocks of this concrete have been placed on decks and used as firewalls of tankers likely to be subjected to bombing attacks. Also it has been specified by the Army and Navy for use on roofs of some temporary and permanent buildings in defense areas.

Certain dry plastic ingredients are added to vermiculite aggregate that is to be used in extremely lightweight, highly insulative concrete for underground heated pipes. This concrete is said to have found special usefulness in Alaska.

## Plasters

Vermiculite-gypsum plasters are of three major types: Regular hardwall plaster, fireproofing plasters and acoustic plasters. The latter type has minor importance, having been largely replaced by vermiculite acoustic plastics.

Vermiculite aggregate is used in hardwall plaster because of its acoustic and thermal insulating properties, fire-resisting qualities, nailability and sawability, etc. Vermiculite plaster is said to require a somewhat longer drying time than comparable sand or perlite plasters.

Vermiculite-gypsum mixes are useful for plaster fireproofing roofs, floors, columns, beams, girders, and trusses. Members so protected have received numerous 3- and 4-hour fire ratings, in tests conducted in accordance with American Society for Testing Materials standard fire test, from such testing laboratories as Underwriters Laboratories, Inc., and National Bureau of Standards.

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[12] Lange, H. K., Vermiculite Insulating Concrete: Rock Products, vol. 48, No. 2, February 1945, pp. 114-116, 119.
Varley, E. R., see work cited in footnote 6, p. 20
Murdock, T. G., and Hunter, C. E., The Vermiculite Deposits of North Carolina: North Carolina Dept. of Conservation and Development, Div. of Min. Resources, Bull. 50, 1946, 44 pp.

A novel use for vermiculite plaster is in making imitation marble by a process of travertine plastering.

## Insulating Cement

A vermiculite insulating cement, made with a suitable heat-resistant binder, is applied as a plastic mass and dried in place. It is an effective insulating material on surfaces operating at temperatures between 100° and 1,800° F.

## Molded Articles and Compositions

Exfoliated vermiculite may be bonded with numerous binders, for example, dextrin, casein glue, fire clay, plaster of Paris, cement, synthetic resin, etc., to produce thermal plasters, fireproof boards, plastic refractory insulation, molded articles, etc. In combination with asphalt, exfoliated vermiculite is also utilized in producing various roofing and flooring compositions and in manufacturing tar adhesives.

## Refractory Insulation

Refractory insulation of several types is made with vermiculite. On the roofs of furnaces and kilns, vermiculite can be used in the form of loose fill, which is in turn covered with vermiculite cement. Vermiculite bricks bonded with such materials as portland cement, fire clay, sodium silicate, etc., are used for high-temperature insulation, particularly for the insulation arches of open-hearth furnaces,13/ where structural strength of the brick is not essential, for insulating oil-refinery units,14/ where a higher proportion of binder is used to obtain higher strength, and for similar installations.

## Agricultural Uses

Exfoliated vermiculite is used as a soil additive for rooting cuttings and tubers, in hotbeds for sprouting seedlings and starting flowers, and as a general soil conditioner, mainly to lighten heavy clay soil and to improve its moisture-retention qualities.

To lighten heavy soils for growing leguminous crops, an exfoliated vermiculite of somewhat heavier grade than that used for insulation purposes is said to find considerable favor in the vicinity of small deposits of crude vermiculite in North and South Carolina. A study has been made of the qualities imparted to soils by the addition of exfoliated vermiculite.15/

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13/ Varley, E. R., see work cited in footnote 6, p. 25.

14/ Sanders, T. P., Vermiculite Finding Increasing Application in Oil Industry: Oil and Gas Jour., vol. 40, No. 12, July 31, 1941, pp. 155-156.

15/ Bureau of Mines, Vermiculite (Soil Tests): Mineral Trade Notes, vol. 32, No. 3, March 1951, pp. 53-59.

This grade of vermiculite also is used to a considerable extent in some areas as a bulking agent, or anticaking material, in fertilizer.

## Acoustic Plastic

Acoustic plastic is composed of a large proportion of vermiculite mixed with fibrous materials and a binder. In contrast to plaster, the plastic contains no setting agent and will soften when wetted. It is applied like plaster to any surface that is clean and water-resistant. Improved acoustical effects are obtained with the material in homes, studios, offices, and stores. It has a high noise-reduction coefficient and the light weight and fire resistance of vermiculite plaster.

## Uses for Unexpanded Vermiculite

Unexfoliated vermiculite has a few minor uses. It may be used as a filler to increase the fire resistance of wallboard and other manufactured items. Ferrosilica briquets containing vermiculite when dropped into liquid metal are quickly dispersed owing to the expansion characteristics of the vermiculite. When circulated in drilling muds, "delaminated" vermiculite is said to assist in sealing off porous formations, thereby lessening mud loss.

"Lamisilite" is unexfoliated, graded vermiculite leached with hot, concentrated acid to produce pure silica in flake form. The product is used as a dehydrating medium in air-conditioning plants and as a catalyst in preparing organic compounds, such as petroleum hydrocarbons.

## Competitive Products

Exfoliated vermiculite encounters competition in all of its fields of use. Competitive concrete aggregates include sand, gravel, stone, air-cooled slag, and such lightweight materials as expanded clay and shale, foamed slag, expanded perlite, cinder, pumice, scoria, and diatomaceous earth. Vermiculite concrete competes with other insulating and structural products. Competing plaster aggregates include sand, expanded perlite, and pumicite. Other loose-fill insulation materials include mineral wool, diatomite powder, and expanded perlite. A wide variety of materials is used for industrial insulation, including mineral wool, asbestos sheet, 85-percent magnesia, silica aerogel, fiber glass, "foamglas," diatomite products, and vegetable fibers. As a soil conditioner (not a fertilizer), vermiculite competes with expanded perlite, peat, and peat moss, straw mulch, leaf mold, plant stalks, and other agricultural waste products. As a carrier of chemicals it is used in place of numerous kinds of natural and artificial dusts.

In all of its minor applications it invades markets formerly held by other products, and its use in each case depends on considerations of economy, utility, or both.

## PRODUCTION, CONSUMPTION AND PRICES

### Crude

Production data for 1924 through 1951 are given in table 1. Figures for the early years of activity in the vermiculite industry may be somewhat incomplete. Although commercial production of vermiculite began in 1915, until 1924 the yearly production was reported as a part of the mica total or under the heading "Minerals allied to mica."

The designation "screened and cleaned" was not adopted until 1944, although most of the earlier figures may also be assumed to refer to furnace-grade material. The values given for 1924-31 are obviously too high to refer to the crude and probably are for the exfoliated product. During those years prices of crude vermiculite concentrates ranged from $6 to $12 per short ton.

TABLE 1. - Screened and cleaned vermiculite sold or used by producers in the United States, 1924-51[1]

| Year | Quantity, short tons | Value, f.o.b. mill |
|---|---|---|
| 1924 | 2 | $68 |
| 1925 | 102 | 2,818 |
| 1926 | 150 | 3,750 |
| 1927 | 51 | 1,318 |
| 1928 | 1,006 | 38,118 |
| 1929 | 982 | 24,483 |
| 1930 | 831 | 13,682 |
| 1931 | 1,256 | 24,758 |
| 1932 | 1,643 | 16,950 |
| 1933 | 2,247 | 21,993 |
| 1934 | 4,746 | 56,965 |
| 1935 | 7,068 | 88,485 |
| 1936 | 16,933 | 185,787 |
| 1937 | 26,556 | 260,664 |
| 1938 | 20,700 | 192,000 |
| 1939 | 21,174 | 174,587 |
| 1940 | 22,299 | 137,698 |
| 1941 | 23,438 | 125,444 |
| 1942 | 57,848 | 319,931 |
| 1943 | 46,645 | 471,595 |
| 1944 | 54,116 | 541,744 |
| 1945 | 64,808 | 648,077 |
| 1946 | 86,390 | 867,973 |
| 1947 | 131,385 | 1,338,572 |
| 1948 | 138,635 | 1,387,233 |
| 1949 | 168,819 | 1,686,419 |
| 1950 | 208,096 | 2,122,427 |
| 1951 | 209,008 | 2,093,953 |

[1] Source: Bureau of Mines, Minerals Yearbooks, Minor Nonmetals chapters.

Through the years the price of crude concentrates has been steady. As shown in the table, the average mill value has approximated $10 per short ton since 1943. The Zonolite Co. usually quotes prices of screened, dried, and sized material f.o.b. cars at railhead. Present price for Montana material in the larger sizes is about $13.50 per short ton and for the smaller aggregate sizes $12 per ton. The price of South Carolina concentrates is about $12 per ton.

Nearly all imports of crude vermiculite come from deposits in the Union of South Africa, particularly from the Palabora area, Transvaal, and are used by exfoliating plants in the New York City area and in Eastern and Southern States. In 1950 the United States imported from the Union of South Africa 18,515 short tons, valued at $256,152, f.o.b. port of shipment - an average of $13.83 per ton. However, in 1951 the quantity imported from that source declined to 11,110 short tons, valued at $142,184, f.o.b. port of shipment - an average of $12.80 per ton. With the addition of freight charges the cost of African vermiculite to eastern producers is about the same as that of vermiculite from Libby - approximately $30 per short ton.

## Exfoliated

The Bureau of Mines has never conducted an annual canvass of production of exfoliated vermiculite. In Minerals Yearbook it has been customary to assume a 5-percent loss of moisture weight during exfoliation (10 percent was the assumed loss before 1946) and to then assign an average value of $75 per short ton ($80 in 1950-51) to the derived figure. Using this method, the quantity and value of exfoliated vermiculite produced and sold in the United States during the years 1943-51 are shown in table 2. However, some of those familiar with the industry believe that the true average mill value is somewhat less than the above figure.

There are about 50 vermiculite exfoliation plants in the United States.

The price of exfoliated vermiculite, f.o.b. plant, in quantity lots to jobbers, is usually between $0.80 and $1.10 per 4-cu. ft. paper bag, which usually weighs 24 to 32 pounds. The price to the consumer is then determined by the handling costs, freight charges, and dealer's markup. Different grades of exfoliated material sell for slightly different prices.

TABLE 2. - Exfoliated vermiculite sold or used by producers in the United States, 1943-51[1]

| Year | Estimated quantity, short tons | Value | |
|---|---|---|---|
| | | Est. ave. per short ton | Estimated total |
| 1943 | 43,333 | $75 | $3,250,000 |
| 1944 | 48,704 | 75 | 3,652,800 |
| 1945 | 58,333 | 75 | 4,375,000 |
| 1946 | 82,067 | 75 | 6,155,000 |
| 1947 | 124,813 | 75 | 9,361,000 |
| 1948 | 131,707 | 75 | 9,878,000 |
| 1949 | 160,373 | 75 | 12,028,000 |
| 1950 | 200,000 | 80 | 16,000,000 |
| 1951 | 200,000 | 80 | 16,000,000 |

[1] Source: Bureau of Mines, Minerals Yearbooks, Minor Nonmetals chapters. No estimates of quantity and value of exfoliated vermiculite were made before 1943

(Up-to-date list of vermiculite-exfoliating plants is available without charge from Minerals Division, Bureau of Mines, Department of the Interior, Washington 25, D. C.)

## Vermiculite processing plants in the United States

### ALABAMA

(1) Alabama Vermiculite Co.
Empire Building
Birmingham

(2) Southern Zonolite Co.
2800 Fifth Ave., S., Ave. E
Birmingham

### ARIZONA

(1) Ari-Zonolite Co.
Glendale

### ARKANSAS

(1) Dixie Lane
Little Rock

### CALIFORNIA

(1) Arabian American Oil Co.
22 Battery St.
San Francisco 11

(2) California Zonolite Co.
208 Jibbon St.
Sacramento

(3) California Zonolite Co.
5440 San Fernando Rd., West
Los Angeles 39

### COLORADO

(1) Western Mineral Products Co.
111 S. Navajo St.
Denver

### DISTRICT OF COLUMBIA

(1) Vermiculite Products Co.
1911 Kenilworth Ave., N. E.

### FLORIDA

(1) Seaboard Vermiculite Corp.
Boca Raton

(2) Southern Zonolite Co.
1530 East Adams St.
Jacksonville

(3) Southern Zonolite Co.
35th and Third Sts.
Tampa

### ILLINOIS

(1) International Vermiculite Co.
Girard

(2) F. E. Schundler & Co., Inc.
DeKalb

(3) F. E. Schundler & Co., Inc.
504 Railroad St.
Joliet

(4) Zonolite Co.
12300 S. Ashland St.
Blue Island

### KANSAS

(1) Dodson Manufacturing Co.
1463 Barwise St.
Wichita

### KENTUCKY

(1) Zonolite Co.
Wilders (Newport)

### LOUISIANA

(1) Southern Mineralite Co.
2933 Dauphine St.
New Orleans

### MARYLAND

(1) Vermiculite Products Corp.
631 Equitable Building
Baltimore

### MASSACHUSETTS

(1) California Stucco Products,Inc.
169 Waverly St.
Cambridge

### MICHIGAN

(1) Zonolite Co.
14300 Henn St.
Dearborn

### MINNESOTA

(1) McArthur Co.
936 Raymond Ave.
St. Paul

(2) B. F. Nelson Mfg. Co.
401 Main St., N. E.
Minneapolis 13

(3) Western Mineral Products Co.
1720 Madison St., N. E.
Minneapolis 13

### MISSOURI

(1) Eagle-Picher Lead Co.
Insulation Division
Joplin

(2) Vermiculite Products Co.
515 Madison St.
Kansas City

(3) Zonolite Insulation Co.
5100 Manchester Ave.
St. Louis

### MONTANA

(1) Robinson Insulation Co.
12th St. N. and Riber Dr.
Great Falls

(2) Zonolite Co.
Libby

### NEBRASKA

(1) Western Mineral Products Co.
36th & 1st Sts.
Omaha 7

### NEW JERSEY

(1) American Vermiculite Products Corp.
South Kearney

(2) Vermiculite Industrial Corp.
Gilligan St.
Port Newark

(3) Zonolite Co.
336 Whitehead St.
E. Trenton

### NEW MEXICO

(1) Southwest Vermiculite Co.
1822 N. First St.
Albuquerque

### NEW YORK

(1) The Carborundum Co.
Niagara Falls

(2) F. E. Schundler & Co., Inc.
45-15 Vernon Blvd.
Long Island City

(3) Zonolite Co.
N.Ferry & Water Sts.
Albany

### NORTH CAROLINA

(1) American Vermiculite Co.
Spruce Pine

(2) Carolina Vermiculite Co.
High Point

(3) Minerals Inc.
Franklin

(4) Southern Vermiculite Co.
Franklin

NORTH DAKOTA

(1) Robinson Insulation Co.
Minot

OHIO

(1) Wyodak Chemical Co.
4600 East 71st St.
Cleveland

OREGON

(1) Vermiculite - Northwest, Inc.
2303 N. Harding Ave.
Portland

PENNSYLVANIA

(1) Harbison-Walker Refractories Co.
Clearfield

(2) Hyzer and Lewellen
Southampton

(3) Zonolite Co.
23rd and Pa. R. R.
Pittsburgh

SOUTH CAROLINA

(1) Zonolite Co.
Travelers Rest

TENNESSEE

(1) Zonolite Co.
Thompson Lane
Nashville

TEXAS

(1) Texas Vermiculite Co.
Burnet

UTAH

(1) Intermountain Insulation Co.
33 W. First St.
Salt Lake City

WASHINGTON

(1) Vermiculite-Northwest, Inc.
1318 Maple St.
Spokane 12

WISCONSIN

(1) Western Mineral Products Co.
525 West Oregon St.
Milwaukee 4

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